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A PERFORMANCE MEASUREMENT AND IMPLEMENTATION METHODOLOGY IN A DEPARTMENT OF DEFENSE CIM ENVIRONMENT

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Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

The Naval Air Depot (NADEP) at Cherry Point, NC, is a multi-purpose facility primarily responsible for the repair and maintenance of Navy/Marine Corps aircraft. ~~The focus of this study will concern~~ the economics and performance of the repair of damaged and worn jet engine turbine blades and vanes.

Although the business climate and considerations of a government not-for-profit operation are uniquely different from a commercial operation, the NADEP will, in many respects, compete for business as if it were operated for profit. Not only will the Cherry Point facility compete with other NADEPs, but Cherry Point will compete with commercial repair operations such as those run by the major airlines. Because the Navy does not have the capacity to make repairs for all its blade and vane repairs, it must therefore subcontract a varying fraction of its repairs commercially.

Improvements in the NADEP's blade and vane repair capability, coupled with the decision to build a more modern facility, should put the managers at the NADEP in a unique position. Recent enhancements have enabled NADEP Cherry Point to perform repairs at a tremendous savings over what was formerly being paid to outside contractors, who essentially monopolized on the NADEP's inability to conduct internal repairs. In fact, these savings are underwriting the cost of the new facility in its entirety. The result is that future decisions concerning how much work to contract out will be based more on cost and less on capacity, which is the limiting factor until the new facility is operational.

Because of the savings mentioned above, the economic justification for the decision to build the new facility has essentially been completed. The economic evaluation to be conducted here is more concerned with monitoring economic performance as a basis for decision making than for initial justification.

The NADEP is in the early stages of what is roughly a 5-year, 3-phased Computer Integrated Manufacturing (CIM) effort to automate the repair function of the blades and vanes. The new facility is currently being called the Engine Blade/Vane Facility (EB/VF). There are three primary goals in automating this process. The first goal is to increase the blade/vane repair rate of production throughput by at least an order of magnitude over what is achievable through current blade/vane repair operations. The schedule for achieving this increased rate is as shown in Figure 1. The second goal in automating the facility will be to ensure that the level of quality will remain as high or higher than current operations as this significant increase in production rate occurs. A third goal is to achieve the prior two at a substantial discount over what the blade repairs would cost commercially.

In 1983, the Blade Repair Program Office was established to develop and qualify repairs for condemned blades and vanes. Since then, much of the technology envisioned for the CIM Facility has been and is being tested in the "Interim Facility", a laboratory-type operation on the premises. Even as the CIM environment evolves, the Interim Facility will continue to operate as a proving ground for emerging blade repair applications, in

the hopes that one day the enabling technologies will see utility in the new facility [31].

To minimize risk, plans call for three phases of computer integration. The efforts in the first phase will focus on acquiring and installing the machine tool equipment, along with their associated NC computer equipment. The first phase effort will also involve the acquisition of the computer equipment that will support the implementation of the Automated Guided Vehicles (AGVs) and the Automated Storage/Retrieval System (AS/RS).

In addition, Phase I efforts will initiate the phased development of software simulation tools. These tools will be developed to support risk minimization analyses that will be performed prior to the initiation of each succeeding implementation phase. The overall objective of these analyses is to ensure that the planned production rates can be economically achieved prior to significant investments into new technology. Once the three phase implementation is complete, the simulation tools developed will be used to perform ongoing evaluations of day to day plant operations that result from the interactive rescheduling of specific job assignments.

The second phase implementation effort will focus on acquiring and integrating the Work Cell Managers (WCMs). These WCMs will coordinate the activities of multiple sets of numerically controlled machines on the shop floor.

The third and final phase of implementation will focus on integrating the coordination of all WCM subsystems into a functional CIM operation. The development and implementation of the simulation modules will be incremental and parallel to the incorporation of the higher levels of CIM implemetation [41].

1.2 Schedule

The schedule for the execution of these tasks is as follows:

Requirements and Needs Analysis	Aug 88 - Nov 89
Occupancy in New CIM Facility	Oct 89
Detailed Design (Equipment Installation, Work Cell Creation/Integration, Full Plant Integration)	Nov 89 - Jan 92
Interim Support	Jan 92 - Jan 93

1.3 Problem Definition

The Structured System Specification (dtd 1 May 87) calls for a systems engineering approach to the integration effort, to incorporate "a risk analysis/design management element, as well as significant involvement with the artisans and production personnel in the system design. The combination of the two elements will provide a solid foundation for

return on investment predictions that will be performed prior to the next phase implementation occuring. The next phase implementation will not begin unless the return on investment (ROI) projections meet satisfactory levels [41]."

The defined task of this effort will be to develop a decision tool to gauge whether or not to proceed, and to what extent, into the next phase of implementation. Inherent in this approach is an ability to measure performance. Although called for in documentation, no defined methodology exists for government personnel to make these kinds of decisions. All decisions must be economically justifiable and in keeping with prescribed NADEP goals.

1.4 The Military Environment

One marked difference in this study that makes it unique is the fact that the operation is run by the Federal Government. Therefore, there are several considerations that distinguish the operation from a private venture. First, the nature of the economic justification to pursue the project is inherently different. The terms "return on investment" and "discounted cash flows" are not as relevant in this scenario. Rather, the venture is initially justified primarily on its ability to compete with the prices the NADEP had been paying outside contractors to conduct the blade repairs. The prices the outside vendors had been charging were indeed exorbidant and provided a strong stimulus to undertake the CIM venture.

Second, because it is a government effort, the management is not accountable to the shareholders per se, but to higher Marine Corps command, Congress, and indirectly to taxpayers. The effect here is to prolong the time during which the facility will be scrutinized. For instance, a given return or dividend will not necessarily be achieved on a quarterly or yearly increment. Rather, a different set of parameters to judge the extent of success must be established.

It is for this very reason that a non-standard yet scientific approach to performance measurement is so critical. In an era of heightened concern over budget reductions, especially in the Department of Defense, accurate documentation of benefits derived for dollars spent is essential. Not only does it provide a valuable internal management tool, but it serves external purposes as a means of reporting performance to outside sources (i.e. Congressional inquiries).

2 Literature Review

2.1 Introduction

A literature review was conducted with several goals in mind. First, a search was conducted for relevant techniques and information which would apply directly to the issues faced. Second, the academic nature of the research consulted would provide for a more scientific appreciation for and approach to the problem at hand. Third, the literature research would hopefully spawn insight into related topics in the broad scope of CIM.

Because of the nature of the problem as described earlier, the search led primarily into the areas of CIM Justification, Automation Strategies, Performance Measurement, and Integration issues. Of these, perhaps the one area possessing the greatest volume of treatment and information is the justification of CIM-related (automated) capital expenditures. Although many articles branched into related and more diverse economic considerations, the primary focus of most articles found was the economic justification of CIM expenditures, assuming that the current mode of operation was not automated or minimally automated.

The economic justification, then, is in theory provided to support a go/no go type of decision in terms of plant automation. While there is a wealth of good information on which to base these types of decisions, the nature of the challenge at the NADEP renders much of it irrelevant. Namely, the decision to proceed into what the NADEP calls "Phase I" (the first level of automation) has already been made. Therefore, the focus becomes *to what extent* as opposed to automating at all.

Also, because of the nature of the Government budgetary system, the process of funding appropriations is virtually irreversible. The justification to undertake this CIM effort, based on the Interim Facility's ability to repair blades and vanes at a cost competitive with commercial firms, has already been completed. The funds to do much of the preliminary work have already been "flowing". Because the effort (such as design, preliminary construction, etc.) is so lengthy, it will take at least several years before concrete assessments can be made in terms of the degree of progress being made toward ultimate goals. Therefore, a good deal of money will have been expended before this juncture occurs. Such is the level of commitment of this effort, and such is the risk.

There are basically two schools of thought with respect to conventional approaches (payback, rate of return, etc.) to economic justification of automation expenditures. One is that traditional measures, given the complexities and variables of computer integration, are simply outmoded and ineffectual. The other school of thought is that the measures mentioned are indeed meaningful but are ill-applied.

2.2 Why Automate?

Though automation is not as yet a universal panacea, there are plenty of success stories to at least warrant it real consideration. In a 1982 study by Hutchinson and Holland [21], an experiment was designed to simulate the economic performance of two hypothetical manufacturing environments, one being a Flexible Manufacturing System (FMS) operation, and the other being a Transfer Line (traditional manufacturing) operation. Algorithms were developed for determining capital expenditures for each process. The primary result of interest in this study is that the FMS operation resulted in a 6.1% grand mean cost advantage over the non-automated process. Other advantages of the automated system were the following:

1. ability to reduce over capacity charges by more closely matching capacity to demand,

2. reduction of long-term capital requirements through capacity conversion,

3. short-term conservation of capital through incremental acquisition of capacity, and

4. FMSes exhibited a greater marginal advantage over the Transfer Line as capital costs to variable costs increased.

The simulated results seem to echo those found in real-world scenarios. Successful application have resulted in the following, as concluded by Estes [16]:

1. proven quick return on investment (ROI)

2. productivity improvement from 20% to 60%

3. increase in quality (process, output, etc.)

4. increase in quality of work environment.

Obviously, cases abound where automation implementation could only be deemed a failure. This risk, coupled with the tremendous expenditure required, have caused managers and financiers alike to tread cautiously in pursuing automation ventures. Oftentimes, ventures are undertaken for the wrong reasons. While a full treatment of this topic is beyond the scope of this paper, there are some generalities that can be made with respect to the types of automation/upgrade opportunities warranting further consideration. According to Klipstein [25], the following situations represent such opportunities, which pertain to companies seeking to:

1. reduce manufacturing cost

2. improve product quality

3. increase plant output

4. lower investment

5. broaden output flexibility.

Not to be overlooked in automation decisions are strategic issues. Over the last several decades, the industrial base, which many say is the backbone of our economy and high standard of living, has been steadily eroding. One dangerous trend that has developed in keenly competitive world markets, says Rohan [33], has been for U.S. companies to resort to foreign sourcing to offset the low overseas labor rate. Soon they are importing 30% to 40% and laying off workers. Before long, they are only distributors and not manufacturers. Control over quality is lost, and lack of control over the design process follows. From then on, it is often only a matter of time until some other distributor is able to undercut them and put them out of business. As one can see, the national implications of the continuance of this situation are severe indeed.

2.3 Shortfalls of Traditional Accounting Practices

Many argue that traditional accounting techniques have been one of the greatest hinderances in the pursuit of industrial automation. Because the inherent nature of CIM operations is so radically different from traditional, manually-intensive operations, the accounting system has transitioned even less smoothly than automation in general. For instance, current cost accounting systems are based on direct labor, which is becoming a smaller and smaller percentage of total cost. Also, conserative-minded managers have set artificially high return-on-investment hurdle rates as a hedge against what are considered to be risky ventures.

Another pitfall of potential CIM projects is that they are often evaluated as a stand-alone project, rather than as part of a strategic plan. Because of the network-oriented nature of CIM systems replete with a myriad of peripherals, they cannot be viewed in the context of a one-to-one replacement of existing systems. The old engineering economy relacement analysis, featuring a "challenger" versus a "defender" is no longer applicable for this very reason; namely, the challenger will perform an inherently different and much broader function than the defender.

Overlooking indirect cost reductions has also proven to be an impediment to implementation. As direct costs have shrunk, to as little as 5% of total cost in some industries, the indirect costs, primarily overhead, have become much more of a target of opportunity in the war on cost reductions. Though there are no turn-key solutions, CIM applications have demonstrated the ability to reduce indirect costs in areas such as material handling, inventory control, quality control, engineering design changes, and more. Oftentimes, the benefits in these areas are less tangible and more difficult to identify and control. This should not, however, divorce them from consideration and/or quantification. Though traditional accounting practice has been unable to account for these "soft" benefits, they are becoming more and more prominent, argues Seed [37], especially in light of the longer spans of time that one must allow for the maturity of CIM applications.

While traditional equipment justifications were typically constructed in the "go/no go" mode, the actual choices in automation decisions are much more broad. If the decision is made to introduce industrial automation, one is faced with a broad range of alternatives with respect to the *degree* and *rate* of automation. One could argue that this aspect actually represents the crux of industrial automation today. We shall see later how these types of decisions are coming into play in the NADEP environment.

Because most firms have based decisions on traditional techniques founded on profitability criteria, high technology equipment and systems are often rejected because an artificially high hurdle rate is established [24]. The effect has been to favor the short-term projects at the expense of strategic (CIM) projects, which have the potential of paying handsome dividends in out-years, but at a steeper initial investment, as is shown in Figure 2. The ramifications of this mindset could have serious repercussions for the U.S. economy. Many of the benefits of automation can only be achieved through the successful integration of iterative efforts which take years to conduct. These benefits (such as improved flexibility, better quality, and reduced lead times) are primarily those which

are more difficult to quantify yet have a more substantial impact on indirect cost areas. Because the U.S. is at such a disadvantage in the world market with respect to labor rates, it is these indirect cost aspects which must be targeted.

2.4 New Approaches

Many innovations are two-sided issues; CIM is no exception and is certainly not a panacea, especially if ill-applied. For example, if a company, even for good strategic reasons, consistently invests in projects whose financial returns are below the cost of capital, it will be on the road to insolvency. Whatever the special values of CIM technology, they cannot reverse the logic of the time value of money.

Fortunately, new approaches are proving invaluable in overcoming many of the aforementioned barriers to CIM implementation. However, a fundamental change in the way automation is approached is required before these techniques can transpire. For instance, automation justification gives rise to three unique considerations:

1. a dynamic environment in which many traditional machines and processes are eliminated
2. functions to be accomplished are time-variant and become integrated over time.
3. the tendency to move toward strategic motives.

What we have seen is a lag between automation technology and the financial tools to implement that technology. A cost accounting system is a mirror of the manufacturing process. As the manufacturing processes are changing, so must the cost accounting change. But the problem area has not been so much with mechanics of accounting techniques, as with the proper application. The reason is that so many of the benefits of an automated solution are considered intangible (less scrap, better quality, reduced inventories, etc.). Even though intangible benefits may be difficult to quantify, Klipstein [25] states that there is still no reason to value them at zero in capital expenditure analysis. New estimating techniques and guidelines are proving helpful in quantifying economic benetfits. Among these are:

1. use of actual production volumes
2. allowance for learning curve effects
3. use of realistic production product mix
4. assumption of less than 100% up time (allow for maintenance, tooling, etc.)
5. use of incremental savings for back-fit, total savings for new plant
6. tolerance of 25% (or some other agreed-upon percentage) short fall in benefits and still consider a project to to successful.

Realistically, a correct alternative to new CIM ventures should assume an initial situation of declining cash flows, market share, and profit margins. With respect to cash flows, a common error is to include the "carrying cost" of inventory in the ROI calculation as the benefit of inventory reduction. To calculate the benefit of inventory properly, says Hinmon [20], carrying costs should be ignored in the ROI. Payback calculations, instead of a reduction in floor area and handling labor (part of the carrying cost), should be separately identified as savings. The value of inventory elimination should be treated as a positive cash flow item directly off-setting the capital investment in the project.

A common application showing promise is to use a discounted cash flow (DCF) methodology (with after-tax internal rates of return and net present values of capital), taking into account these types of considerations and realizing that a more long-term strategic tack must be taken, both with respect to the future of the company, and with respect to the future of the U.S. economy as well. More insight and oversight must take place at the upper tiers of an organization in the application of hurdle rates used to screen potential projects. It is critical to note that the hurdle rate is not and should not be equal to the cost of capital, which is in itself often mistreated. Companies should use a discount rate based on a project's opportunity cost of capital (that is, the return available in the capital markets for investments of the same risk), says Kaplan [24]. The cost of capital, then, should be a composite of the cost of various sources of funds comprising a firm's capital structure. It is the minimum rate of return that must be earned on new investments that will not dilute the interests of the shareholder. In practice, the cost of capital is supposed to be the weighted cost of debt and equity to be employed over the time horizon of the prospective investment [37]. An excellent discussion of the nuances of the cost of capital is provided by Kaplan in Appendix A.

Dornan [13] provides a framework for a decision methodology which considers these and other factors such as risk and estimating techniques. A decision flowchart for what the author calls an "enhanced" analysis is presented and compared to the traditional analysis. It is more complex than the traditional process due to the fact that more factors are considered. Worksheets are provided to aid in the analysis at some of the various decision points. It is important to note that this approach can be tailored to specific objectives and is intended to work within the framework of established accounting methods.

2.5 Outlook/Tools for the Future

Gelders [17] suggests complementing the accounting analysis with other tools which have traditionally not been a part of the accounting domain, such as the following:

1. Break Even Analysis
2. Scenario Analysis
3. Monte Carlo Simulation
4. Decision Tree Analysis

5. Sensitivity Analysis
6. Utility Theory.

These would be utilized primarily to help in the evaluation of alternatives because they provide information which could further differentiate alternatives which may appear relatively equal as a result of the economic analysis alone. The use of simulation could be especially promising since this is a cost-effective way to employ computer resources to conceptualize work environments and work flow. Among the more prominent uses of simulation are in the determination and optimization of parameters such as batch size, intermediate storage capacity, sequencing, and the number of workpiece carriers [47]. The topic of simulation with respect to NADEP applications will be discussed in greater detail in "Other Integration Topics."

2.6 Lessons Learned

Canada and Miller [7] report on the results of a survey of capital investment evaluation techniques from 1959 through 1981. In general, they identify a trend toward, but by no means exclusive of, "sophisticated" or discounted cash flow-based techniques, with only moderate increases in reported use of formal risk-adjustment techniques. It was found that firms typically had multiple methods in use, sometimes even on the same proposal, thus understating that indecisiveness which permeates capital investment analysis of automation projects. The main results of this 1985 survey, showing relative usage of the traditional techniques, are shown in Figures 3 and 4.

As more and more companies have ventured into modernization endeavors, certain generalizations can be made about the experiences, both in terms of pitfalls and opportunities, which have resulted from those firms which have collectively "cut their CIM teeth." This is not to infer that there are not major obstacles yet to be overcome; indeed, there are, but certain intangible traits concerning the treatment of accounting issues have emerged which may suggest strong consideration. For instance, it seems to be imperative that engineers and accountants be cross-trained, just as the designers and manufacturing engineers must eventually be cross-trained so that parts can be designed the way they are to be built. No function can no longer exist in a vaccuum. Also, it is often suggested that cost accounting be positioned under operations in the organizational structure so that the notion of accounting not operating autonomously is reinforced.

2.7 "Principle of Fixity"

One of the more scholarly treatments of the breakdown of costs associated with FMS installation is Scott's presentation of the Flexible Automation Methodology (FAME) [36]. FAME is based on the conceptual dichotomy of "flexible expenditure" and "fixity expenditure." By incorporating techniques for generating robotic system component cost-rate figures, a "Principle of Fixity" is derived which appears to govern the form (in terms of mixture of different types of expenditures) of flexible systems.

With FAME, an important distinction is made between those costs incurred by the flexible, reusable portions of a robotic system, and that expenditure (including design) which is fixed to a particular product design and is of no further benefit when that product is no longer manufactured. A further distinction is made between the costs of the robotic equipment itself and the remaining associated "flexible" equipment.

FAME is based on a conceptual model such that as the number of different products run on robotic systems increases, so the fixity expenditures (comprising equipment and costs fixed to a given product) should be reduced, because it is being turned over more often. The amount spent on equipment and services common to all batches should consequently be increased to compensate.

There is also an important implication that the flexible portion of the system should employ as high a proportion of reusable yet non-robotic equipment as possible, because this is recognized as being faster than purely robotic approaches. The model reflects the notion that the annual production volume possible for a given system increases as the form of the system becomes increasingly "dedicated." The author claims that it is the choice of the appropriate form of the system, which in turn dictates the potential production volume, rather than vice versa. This represents the complete inverse of the conventially held view that it is the production volume which dictates the appropriate form of the system.

The tradeoff between increased production rate and increased waste when, for example, a workcell is (re)configured for a new product design, is embodied in the "Principle of Fixity," which states that:

> *for optimal robotic systems, the proportion of the total cost of the system (net of changes in overheads) which is fixity expenditure, is directly proportional to the total time, throughout its life, that the system is configured as a particular generation.*

In other words, a system with an average total configuration time of, say, one year per product should correctly have twice as much fixity expenditures to total expenditure as a similar system in which each generation only lasts in total for six months.

2.8 Other Integration Topics

Other areas of interest pursued in the literature search were perhaps less tangible and thus more difficult to find information on as scientifically based or universally accepted. The first such topic is systems integration. Once you have made the decision to automate and expend capital, how do you put the pieces together in a cohesive fashion? When one considers the number of variables involved and their interaction, one can begin to gain an appreciation for the complexity of the issue, and also why no one has all the answers. Though certain segments of the problem could be considered deterministic, other aspects must often be approached in a heuristic fashion. Also, while the technical issues of CIM are pushing and even defining state-of-the-art boundaries, it could be argued that CIM is more of a management issue than a technical one.

Warnecke and Scharf [47] discuss the significant criteria that should be considered in the development of Integrated Manufacturing Systems (IMS). They emphasized the need for the following:

- a hierarchical framework
- product range flexibility with adaptive machines
- system integration using automated workpiece handling and tool changing
- "enlargability" of the system
- compatability with other systems.

Their conceptual framework incorporates multiple objectives to compute the system performance index of alternative machine configurations.

The use of simulation, though often exhaustive and costly, is proving to be an invaluable aid in the planning phase of automated systems. In general, the purpose of the type of simulation modelling described by all authors cited in the survey by O'Grady and Menon [30] has been one of the following:

1. to establish the viability of a given FMS configuration of machines and transport devices
2. to assist the system design process with respect to hardware choices
3. test operational planning and control strategies.

The factors generally considered in such studies are:

- the effects of machine and system reliability with respect to breakdown/repair parameters (such as Mean Time Between Failures and Mean Time To Failure) and throughput performance
- the comparison of alternative loading strategies based on priority sequencing rules
- the problems arising from different aspects of system flexibility
- comparison of alternative configurations
- potential congestion of the transport system.

One particularly interesting simulation undertaking (using the GPSS-based event-oriented package called MUSIK) studied the effects of key parameters on the economics of Flexible Manufacturing System (FMS) configurations. Figure 5 shows that the advantages of FMS layouts are readily apparent (in this case) by decreasing batch sizes to a certain limit [47].

A parallel effort being pursued at NADEP Cherry Point involves the use of simulation and linear programming tools being developed in the N.C. State University Industrial Engineering department as a production planning aid. The model currently consists of a central warehouse for database management and three separate working modules. The databases contain information on the machines to be employed in conducting blade repairs, such as the various types and quantities of machines at hand. In addition, blade repair parameters (standard times for given repairs, standard routings, etc.) are maintained in the central database. These databases interact with each of the three modules and provide current data necessary for the linear programming and simulation execution.

The first module, the *Menu* module, is a means to conduct data manipulation via easy access to databases. The interactive, menu-driven format enables the user to conduct data updates quickly and efficiently. In fact, in order to better insure widespread use of the system, the personnel at the NADEP Cherry Point have provided constant input and feedback (primarily with respect to formatting) in the design of this and all features of the model.

The second module, the *MenuLP* module, is a linear programming module. The decision variable is the number of a given type of blades to repair in the planning horizon. The objective function, then, is to maximize the weighted throughput (Q) of collective blade repairs. The weight assigned to each blade repair is a relative index which depicts the relative worth of a given blade repair versus the other blade repairs. An obvious example of this worth is profit for each type of blade repair, though there are different approaches which could be taken in assessing relative weight/worth, some of which are more subjective than others. Expressed mathematically, then, the linear programming module is as follows:

Weighted Throughput$Q = \sum_{i=1}^{M}(C_i X_i)$
such that
$\sum_{i=1}^{M}(A_{ij} X_i) < B_j \qquad j = 1, \ldots N$
$(X_i) > 0$

where:
C_i = weighted worth of given blade repair
X_i = number of given blade to be repaired
A_{ij} = cost (in hours) of a repair i on machine j
B_j = capacity (hours available) for machine j
M = total number of different blade types
N = total number of machines

What appears to be a simple model (which it is) can therefore be useful and powerful, especially in the absence of other tools, which seems to be the case at the NADEP. The result is a "first pass" analysis which forms a defensible starting point from which to conduct a more refined analysis. One refinement being developed at this stage is a

sensitivity analysis which will enable a user to see the relative effects on the objective function of altering parameters (one at a time, with others held constant) to the extent that the assumed decision (product mix) is changed. The range of the changes for each of these parameters can then be examined in a relative sense to see which are more "volatile" in affecting decisions.

The third and final module, the *BrfSim* module, is the simulation model which can further introduce refinements to the results of linear programming. The Monte Carlo simulation techniques are especially powerful because of the ability to process huge amounts of data and generate useful production planning information *without* having to actually commit hardware and other resources, which can be very costly. For instance, by using induction levels derived by the linear programming model, one can construct layout scenarios for a given planning horizon. The simulation can then yield such parameters as machine utilization rates, turnaround time, and average delay times. If the results are unfavorable, or if there is reason to believe a different set of parameters will yield better results, the inputs to both the linear program and simulation models can be altered in an iterative fashion until the "optimal" layout/induction mix is achieved. There are obviously key assumptions and subjective inputs which must be made, but the point is that a powerful, computer-based, cost-effective decision tool(s) is available, the results of which can only improve as hard data becomes available. It is important to note that as the facility matures, these models can be refined to grow with the facility and therefore continue to be of continued service to the NADEP. The model would then become less of a planning tool and more of an operational tool.

There appears to be a golden opportunity to link the simulation/linear programming model at North Carolina State and the efforts of this study. Because the performance measurement proposal is only indirectly related to short term scheduling, there is little opportunity to tie the linear programming model to this proposal. The scheduling, then, is perceived to be more or less a constant before and after a performance index evaluation. The simulation model, on the other hand, presents ample opportunity to relate the two studies. That opportunity is realized when using a performance index in conjunction with an implementation guide in making future decisions on automation alternatives.

The simulation model can provide information on key parameters (such as machine utilization, turnaround time, and average delay) that will help quantify different machine configurations. The Implementation Guide (see Table 3) as it exists calls for the subjective assessments of future degrees of the automation. The simulation effort represents a means to better evaluate the various scenarios, versus what would often literally be educated guesses on the part of experienced personnel. Not all factors in the Implementation Guide could be evaluated using simulation. Because the simulation currently does not consider reliability/failure or cost concerns, those parameters in the performance index which pertain to these issues will not be affected. But the remaining parameters (i.e. Throughput, Throughput Time, Equipment Utilization, WIP vs. Idle Time) can all be evaluated via simulation.

To employ the N.C. State simulation model, various sets of inputs must be constructed

corresponding to the range of alternatives as depicted in the Implementation Guide, ranging from no new implementation to complete automation in the next phase. The results of the simulation can then serve as a more plausible input to better evaluate the automation scenarios. For instance, depending on the batch size, number of machines in a workcell, process and queue time assumptions, viable estimates of equipment utilization (or other parameters) can be achieved through simulation. These results are then factored into the overall formula for finding the total benefit of an alternative. What makes the simulation model so attractive is the ability to consider the machine layout in a global fashion so as to evaluate the dynamic interaction of the entire environment. In addition, the scenarios can be easily altered and then re-simulated in order to present a range of information over a broad spectrum of possibilities.

As alluded to before, the alternatives in implementing automation (to whatever degree) are as countless as the industries involved. One rule of thumb, however, that seems to be universal concerns the rate at which to approach integrated manufacturing. The consensus is a resounding *slowly and sequentially*. This is commonly referred to as the modular approach [34]. There are a myriad of horror stories where companies simply tried to automate for automation's sake and sunk countless dollars into systems that did not fit the long-term needs of the company. This was especially true in the early to mid 1980s when acronyms like CAD/CAM and CIM became buzzwords and a collective panacea for a depressed U.S. industrial base. Unfortunately, many automation projects were championed by well-intentioned yet short-sighted upper managers. Although some of the requisite technology was available, the expertise in managing the interfacing, implementation, and accounting for such efforts was sorely lacking by personnel across the spectrum, from design engineers to accountants to machinists. Also, some of the resident technical issues, namely, transferability of data and standardization, have proven to have more stamina than originally expected. In short, it seems as if many bit off more than could be chewed, and consequently the U.S. has been playing catch-up to Japan and Western Europe ever since.

Basically, the modular approach assumes a more incremental, strategic approach to the issue of automation. Because even successful, well-planned ventures can span 3 to 5 years, the focus on the piecemeal approach is interoperability and flexibility. The operative question is ... how will this piece of machinery (or software or workcell) adapt to changing conditions downstream? If the acquisition in question cannot fit into the overall schema for the company, then it should not merit further consideration.

The complexity of such an undertaking cannot be underestimated. It must be recognized that no single vendor can install a complete CIM system in any particular plant, as detailed by Teresko [45]. The modular approach lends itself to local computer power, but the database design issue is still very much unresolved. Central databases may work well for many companies, whereas distributed systems may be better for other applications. One obvious goal is to have both the CAD and CAM functions operating from like databases, with the added capability of having CAM hardware and controllers operate directly from the CAD data files.

3 Methodology

3.1 Introduction

As mentioned before, the crux of this project will be a two-phased approach to the integration effort at the NADEP. Basically, two questions will be addressed:

1. How does one measure how well the new facility is performing? and

2. At what rate do you integrate technology and automation into the new facility?

Treatment of the first question will entail the development of what will be called a Performance Index, which will be an encompassing number representing the total cost and pertinent considerations of blade repair operations over a specified period of time. The cost generated will be a cost per blade repair, where the blade in question will be a generic blade to be discussed in more detail in a later section. The cost per blade repaired can be compared to dollars invested in the facility to give a relative measure of merit for the performance of the CIM dollar. The index should be tracked graphically to assess trends. The first data point will be the cost per blade repair (all buy scenario) versus monies invested. Once the first level of integration is implemented, the figures are re-calculated. Hopefully, the cost per blade repair decreases and this would represent savings and productivity improvement in the new operation.

The nature of the second question is such that it does not lend itself to an approach which is as structured as with the first question. This is due primarily to the fact that there are so many variables and unknowns to contend with. Also, because the subject of system integration is so new and the technology involved is changing so rapidly, there is simply not a large enough knowledge base capable of producing tried and true axioms with respect to what course of action to take in which circumstance. One effect is that there is a myriad of vendors competing for business in this market, some who preach what simply is not feasible at this stage, i.e., a one-vendor turn-key solution to systems integration.

The approach taken will utilize Multi-Attribute Decision Analysis, estimating techniques, Benefit-to-Cost ratios, and the aforementioned Performance Index to develop a gauge to address the issue of integration. Because it deals with future data and predictions, the results will be more fuzzy than with the Performance Index. However, recognition of this fact does not render the study less viable. The mere quantification of a situation lays the foundation for better decision making. Indeed, until you can measure something, how can you claim to control it?

3.2 Assumptions

Before proceeding, one must specify assumptions, especially in a situation such as this where unknowns abound. The following is a list of the most pertinent:

1. Demand of blades - One must make an estimate of the number of blades to be purchased and repaired in the first year of operations, or the first definable, meaningful unit cf time. This is the baseline that represents the cost of repairs if the CIM facility were not in existence. In other words, what could it cost to simply go out and buy on the market all the blades (estimated) required in the field this year? Historical data can play a role here; however, the inductance rate is highly unstable.

2. Development of a Generic Blade - Because the composition of blade types repaired i. so variable, a composite blade will be structured. This blade will represent, as best as can be determined, the "average" blade. The percent composition of different types of blades in this average blade will then be used to compile the cost of an average blade repair. Modifications to this generic blade will be required if the composition of inducted blades varies substantially.

3. The goal of 350,000 blades processed will not be achieved, at least in the first several years of operation. This is based on evaluation by NADEP personnel. Therefore, a goal of 350,000 blades will not be factored into the Performance Index but will be treated externally as a goal.

4. The baseline will be an "all-buy" scenario and will not be the Interim Facility costs, as originally projected. Because of the unique operations of the Interim Facility, capturing costs is difficult at best. Also, the CIM facility is to be judged first and foremost on the savings relative to an all-buy mode (if all blades were purchased through outside contractors).

5. All monies allocated to the CIM effort will be expended. In other words, there will be no fiscal year-end budget remaining.

6. The justification for proceeding into Phase I need not be considered. Rather, the extent to which the NADEP proceeds into the integration effort is an issue.

7. A standard lot size of blades processed will be used in the cost/blade calculation. This lot size should be large enough to be representative yet small enough to be responsive. Also, the lot size can be considered as a moving average to reflect the most current conditions.

8. A base year for making financial comparisons will be designated, thereby considering the time value of money in comparing cash flows at different points in time. The interest rate to be used could be the prime rate, which is the opportunity cost to taxpayers for having their tax money put to this application rather than being invested elsewhere [11].

3.3 Approach

The Performance Index (PI) is meant to be a living, breathing parameter. The methodology for computing the PI is discussed in Section 4.3, while the evaluation of the PI in

tabular form is shown in Tables 1 and 2. It must be used, recalculated, and reused again to be of any benefit. The method for calculating the PI is executed iteratively as the implementation matures. As one gets enough data points to decipher trends, this index becomes a management tool. Not only will the index be a performance indicator, but it can become a forecasting tool. For instance, it could be utilized to predict what level of investment is required to achieve a given performance index.

The Performance Index will be an aggregate figure comprised of individual indices which should be both measureable and controllable. Obviously, some indices will be more measureable than others. Basically, the Performance Index will consist of parameters in two groups - those that can be dollarized and those that cannot. The non-dollarized parameters are to be included because of the need to take a more tactical approach to the issue of automation, just as the nature of the approach to economic justification of automated systems is also changing. What follows, then, is an outline of the performance parameters (initially considered) in their respective categories.

3.4 Dollarized Parameters

1. Cost Per Blade

   The blade in question here will be the generic blade referred to earlier. It will be a composite representation of the relative mix of the different blades in the business base. Because this mix is always subject to change, the generic blade may require updating. If the updating occurs frequently, one may want to designate and track the cost of a handful of blade types whose demand is fairly constant. The compilation of costs for specific blades should then be administratively simple.

   The cost per blade parameter can be compared to dollars invested in the facility to give a relative measure of merit for the performance of the CIM dollar. Upon increased implementation, the cost per blade repair hopefully decreases and this would represent savings and productivity improvement.

   Given that this approach is sound and viable, there are still important considerations concerning the costs involved. For instance, how does one go about capturing the costs? Which costs are included?

   Basically, all costs, direct and indirect, should be included in the calculations. The attempt here is to structure a cost breakout that is macro enough to preclude exhaustive administrative effort. Because the new facility would not be built were it not for the expected capability to produce new blades, its costs (construction) must also be considered. Another concern is the avoidance of double accounting. Accordingly, the following breakout in terms of gathering costs is proposed:

   (a) Non-operational Costs:

      This is brick and mortar, construction fees, machines procured, work cells, etc. Basically, these are all costs incurred that are required to give you the

capability to repair blades, but yet are not considered value-added costs. These figures should not be difficult to capture since they are measured via contractual agreement, service orders, and the like. Because the system integration effort will be monitored by contractually required cost and schedule control criteria, these costs will also be easily handled. Non-operational costs are therefore start-up costs and should have a finite lifespan once the facility is up and running.

(b) Operational Costs:

This refers to all costs incurred when the repair facility is functional. Operational costs could be split into value-added and non value-added categories, but this could prove cumbersome because labor and energy both have value-added and non value-added components. Therefore, the following major areas should be considered:

i. Labor
   Direct and indirect labor, plus all benefits and other commitments.

ii. Overhead
   All energy obligations. This should be easily determined via power company statements.

iii. Spares
   Any equipment or parts such as tooling, storage, or fixtures which are periodically required.

iv. Maintenance
   Also performed on a service agreement and therefore easily tracked.

v. Other
   Any category which covers those costs not yet accounted for. The idea here has been to develop mutually exclusive categories which comprise the total cost structure for operating the facility.

2. Inventory

As the facility matures, the inventory should, in theory, be driven to a minimum, contributing to the overall efficiency of the operation. The shop floor control system should have the capability to record and track all articles inventoried. Because the composition of the units and their types will be so variable, the inventory should be dollarized in order to produce a meaningful statistic. Dollars tied up in inventory are dollars experiencing no value-added benefit, and consequently should be contained to the minimum extent possible.

3.5 Non-Dollarized Parameters

Non-dollarized parameters are represented in either units or time, or as ratios of the same.

1. Throughput

   The NADEP has produced figures for intermediate goals as they progress toward the ultimate goal of 350,000 blades per year. The necessary controls at both shipping and receiving should be in place to track throughput in terms of units of specific blade repairs.

2. Throughput Time

   This could be the average time to process a blade, or to process a certain type of blade. The clock would start ticking as soon as the blades are inducted and would run until they are shipped. One needs to know, for instance, how long inducted blades have to wait before being processed. Also, it is important to be able to gauge how reactive machine set-up times are to different types of blade repairs.

3. Work-In-Process (WIP) versus Idle Time.

   This parameter represents the percent of time that a blade is in the facility and work is actually being done on it, i.e., it is in a value-added mode. Currently, the average time to process a blade is 23 days, while the amount of time work is actually done on the blade is only 10 hours [10].

4. Blades Per Resource

   This parameter would be used to monitor a specific precious resource, such as engineering manhours.

5. Field Failures Within a Given Time

   The ultimate test of the quality of the blade repairs is field performance.

6. Mean Time Between Failures (MTBF)/ Mean Time To Failure (MTTF)

   Other measures of field performance. These measures would require some kind of cooperative agreement with the users.

7. Equipment Utilization

   This is the percentage of time that a given machine functions while the facility itself is operating.

8. Percent Scrap or Rework

   An internal measure of quality. One is interested, for example, in what percent of blades have to be scrapped due to poor workmanship.

These parameters should be objectively quantified to the fullest extent possible. However, the goals for each is a subjective call. The parameters need not carry equal weight, for that matter. A total weighted score will be developed for the cumulative effect of these based on relative worth. Also, if it is not cost effective, then exhaustive control mechanisms should not be enacted to gather this data. Rather, it could be compiled on a sampling basis.

4 Case Study

4.1 Introduction

Having presented the methodology, this section will address the application of these ideas as a case study. The validity of implementing these techniques in a government complex will be discussed. Also, results of discussions with NADEP personnel will be presented.

A meeting at Cherry Point on August 20, 1987 [19] among representatives of a cross section of the functional areas involved, the parameters as discussed in Section III were debated to determine whether or not they belonged in the Performance Index. The criteria for inclusion into the Performance Index were as follows:

1. Will improvement in the area in question contribute positively to the stated goals as defined by NADEP personnel?

2. Is the parameter controllable, i.e. is the parameter within the sphere of influence of NADEP management?

3. Is the parameter measureable? Can it be sufficiently quantified?

4. Is the data collection for determination of the parameter administratively feasible?

4.2 Parameter Evaluation

The following is a discussion of how the individual parameters were judged at the meeting:

1. Cost Per Blade - Unanimously ratified for inclusion. This has been deemed as the single most important parameter, so much so that earlier discussions had yielded the suggestion that the cost per blade parameter be broken out as a separate entity and treated separately from the Performance Index. (Note: this could still be done and it is in fact recommended that individual parameters be tracked, especially graphically, to assess trends). The cost to repair each blade would stand as the single most recognizable and most often quoted statistic when the NADEP comes under public scrutiny.

2. Inventory - The consensus was that inventory should be included in the Performance Index, to better account for the large amount of money tied up in material. Inventory here does not include WIP inventory, but rather all raw material that has yet to incur any value-added.

3. Throughput - Another parameter which passes all criteria with no difficulty, especially in light of the NADEP's annual repair goals. The annual goals could be broken down into incremental goals, and further explored by looking at specific types of blade or vane repairs.

4. Throughput Time - Included; this is the measure of average time from induction to shipping. This consideration will also aid in capacity planning.

5. WIP Versus Idle Time - Included and meant to be used in conjunction with throughput time. This ratio of "value-added" time versus "non value-added" time will highlight areas of potential time improvements.

6. Blades Per Resource - Will not be included. Originally intended to provide insight into critical resources. NADEP personnel expressed doubt that this parameter would actually reflect shop floor conditions.

7. Number of Field Failures Within a Given Time T - The final measure of quality of product is field performance, in this case, the wear and durability of blades and vanes under flight conditions. Unfortunately, data collection on the part of the users is not deemed to be feasible due to resource constraints. Therefore, the lack of adequate cooperation from field personnel renders this parameter impractical.

8. Mean Time Between Failures (MTBF)/Mean Time To Failure (MTTF) - These items are rejected for inclusion on the same basis as #7 above.

9. Equipment Utilization - This has been judged to be a viable barometer with respect to the performance of the shop floor control system. Where #5 (WIP Versus Idle Time) is concerned primarily with tracking a batch order (a dynamic situation), this parameter looks statically at a particular workcell or machine center.

10. Percent Rework or Percent Scrap - These parameters are included as a gauge that quality is being maintained as production rates are increased. The distinction between the two is straightforward: scrapped items are non-recoverable items that are thrown away, while with reworked items the defect/poor workmanship is not critical enough to render the item useless (i.e. the blade can be salvaged).

4.3 Combining the Parameters into an Aggregate Measure

Though each of these parameters has significance taken individually, an aggregate measure will provide a more global assessment of what is going on in the factory. The technique of ranking and weighting will be used to combine the parameters into a single measure.

The first step in combining the parameters will be to determine a range for each. The range used here is a 1 to 10 scale, but any range could be used as long as all parties were in agreement. The range must be "scattered" enough to be representative of the possible values that the parameter can attain. It is very important that both the worst and best extreme values (corresponding to 1 or 10 depending on whether or not you are seeking to minimize or maximize a particular parameter) are in fact extreme, yet possible. Ideally, it is commonly suggested that the range of possible values between the two extremes will be normally distributed about the "average" value (corresponding to a rating of 5) of the parameter for a specified period under study. This assumes that the best and worst

situations are equally likely but that under most circumstances, performance will cluster primarily about the mean. A less popular assumption is that of a uniform distribution. Also, because we are seeking to improve the Performance Index, the "best" values for the parameter must correspond to 10, whether or not it is numerically superior. For instance, because we are trying to reduce inventory, the inventory number at the 10 end of the scale will actually be lower than the inventory number at the 1 end of the scale (see Table 1).

Once the parameters are rated (by teams if necessary in cases of subjective assessments), they are then weighted according to relative importance in contributing positively to the NADEP's goals. This is obviously a more subjective evaluation and should therefore be treated accordingly. For instance, a team consisting of represented functions should evaluate the set of parameters (anonymously or interactively) for a given unit of time. To arrive at a single set of weights, one could throw out the low and high scores and produce an average of the remaining weights. In this case, the sum of the weights will equal 100, but this is arbitrary.

There are obviously other viable methods for weighting the parameters. One is the Delphi method which is also a team approach, but is more sophisticated in that direct debate is generally replaced by the interchange of information and opinions through a carefully designed sequence of questionnaires. The participants are asked to give their opinions and the reasons for them, and at each successive interrogation they are given new and refined information, in the form of opinion feedback, which is derived from a computed consensus. For example, suppose the mean, upper, and lower quartiles are determined for a given set of ratings. Those values falling outside the lower and upper quartiles are subject to questioning by the panel [8].

The result is typically a new set of ratings. The process continues through successive iterations until further progress toward a consensus appears to be of questionable value in view of the worth of further accuracy of the estimate. Note that this and other techniques apply not only to the evaluation of the weights themselves but to arriving at the scores of the individual parameters.

Another technique of merit is ordinal scaling, which is basically a method of ranking factors in order of preference. A way to check on the internal consistency of relative judgements is the method of paired comparisons, which suggests that the factors be submitted to the decision-maker two at a time for a preference judgement. This analysis typically forms the backbone of a normalized weighting technique [8].

Therefore, what we have is a matrix which could be called a "scorecard". (Again, see Table 1) During the rating period (end of quarter, end of year), the evaluator(s) must assess the condition of each parameter and score it accordingly. This is called the "evaluation rating" for a given rating period.

In our example (see Table 2), this scoring is designated by marking an "X" in the appropriate box corresponding to the evaluation for each parameter. For instance, for cost/blade, the rating is "6", which would correspond to a normalized dollar value within the range shown. Once all the parameter evaluations are completed, the composite Performance Index (PI) can be assessed. Again, in an attempt to extract as much bias from

the evaluation as possible, the final evaluation values should be averages from collective assessments.

The PI itself is therefore the sum total of the parameter's ranking multiplied by the parameter's weight. Expressed mathematically, the index is of the form:

$$\text{P.I.} = \sum_{i=1}^{n} (\text{EVALUATION RATING } i) \times (\text{WEIGHT } i) \text{ for each of } n \text{ parameters}$$

Note that the PI will be established on a scale with 1000 being the maximum, though this is arbitrary. In our example, the sum is 710. This number can then become a data point against which to measure future performance.

Naturally, a system to collect and decipher this data must be enacted, whether it be in an automated or manual fashion. The cost to implement such a system should be offset by the benefits derived, especially since most of the data required for the parameters is already being generated, albeit perhaps not in accessible form. The adoption of this technique (for calculation of PI) should therefore provide a stimulus to tie in independent functions into the overall data management system. The objective would be to have, at some point, all the information necessary to conduct the scoring in an on-line fashion.

4.4 The Implementation Guide

The Performance Index could be of value not only as a snapshot assessment of current operations, but as a forecasting tool for further implementation, thus addressing the second part of this project. For instance, any decision to proceed to the next phase would have to be justified by meeting incremental targets established by management.

The approach for quantitatively considering subsequent phases of automation is similar to developing the Performance Index because it employs multi-attribute analysis. The set of attributes against which each alternative is to be judged will be called "decision criteria" and is outlined as shown in Table 3. It is important that the set of attributes be independent and mutually exclusive, but not necessarily collectively exhaustive. This list will contain all of the parameters considered for calculating the PI, in addition to several additional parameters which will take into account some of the more intangible factors. Two of these intangibles could be reliability and "integrability", the later being of utmost importance. One of the most frequently cited reasons for the failure of factory automation projects is the dissimilarity of purchases over a period of time. In other words, provisions are not taken so that systems can communicate and operate with one another. It is expected, then, that the criticality of this factor be reflected in its relative weight.

Because some of the criteria cannot be dollarized (or quantified at all for that matter), the criteria must be scored in a manner so that they can be considered collectively. The method to achieve this will be the same as is used for the Performance Index scoring, where each factor is judged on a 1 to 10 scale, except that now the scoring is based on percent change from the present status (see Tables 3 and 4). The distribution for each

factor is assumed to be normal with the mean at 5. In addition, because some criteria are more important than others, the factors will be weighted according to relative importance. The fact that the total benefit is based on a maximum score of 1000 is therefore arbitrary due to the scoring range (10) and the total weight (100). The end result of the scoring is a total benefit score for each alternative.

The traditional method of generating benefit-to-cost ratios for alternatives and granting further consideration only to those with ratios greater than 1 is not practical in this case. The reason is that the total benefit cannot be completely dollarized and therefore one would be trying to "compare apples and oranges". One is left with the possibility of perhaps trying to convert the cost of each alternative to an equivalent rating, as is done for the benefits. The risk is that a certain amount of objectivity is lost. For instance, if a 0 to 1000 scale is used to rate the costs (as was done for benefits), how do you go about graduating the scale? What has been particularly frustrating and evident in this area (further implementation of CIM projects) has been the lack of attention given it in the writings and case studies, at least from an accounting perspective. One reason is perhaps that because strategic factors play such an important role in initially justifying the investment, it is *assumed* that continued investments will be made toward the goal of total automation. Another more obvious reason is the inherent difficulty in quantifying the benefits.

The total cost for each alternative is composed of hardware and equipment, personnel requirements, implementation, and software costs. As far as hardware is concerned, the integrated network is typically comprised of three basic building blocks: computers, databases, and programmable controllers. For personnel, the skill level required to function in a CIM environment will be increased; training programs and costs must reflect this emphasis. The implementation and systems integration costs are often underestimated, primarily due to unforeseen complexities. Software cost, too, are difficult to gauge because there are so many environmental factors that can dramatically impact cost. Software also seems to experience a higher frequency of technical and financial fluctuations.

The main point about costs of alternatives, however, is to decide upon a study period (a common denominator for the life of useful service) and consider *all* costs within that study period on a life cycle basis, including such factors as interest and depreciation. To equate cash flows, the costs are converted to present worth or annual worth equivalents. Careful attention must also be given to the distinction between fixed and variable costs, which helps to account for varying degrees of certainty between the estimates [49].

The total benefit can be compared to total cost in ratio form, but that term has little meaning except to get a relative feel for benefit versus cost. In this way, a top two or three candidates can be identified (see Total Benefit scores in Table 4). In theory, each increment of capital investment must justify itself (starting with lowest cost alternative) and an alternative should be compared with an alternative requiring a lower investment only if the latter investment is itself justified. Following this rule, it is interesting to note that the chosen alternative may not necessarily have the greatest individual benefit-to-cost ratio.

The remaining element to be considered is risk and should be used to help make distinctions between the candidate alternatives. Again, the preferred alternative need not have the highest *incremental* benefit-to-cost ratio if the risk of other alternatives are considerably higher; this is a management decision.

Increasing numbers of firms are attempting to quantify risk, as reported in the 1985 survey by Canada [7]. When risk adjustment techniques were in fact reported, the following shows the average percentages of firms using a given technique:

Adjust discount rate	36%
Shorten payback period	22
Use probabilities with cash flows	18
Adjust cash flow conservatively	8
Other	16
Total	100%

Risk assumes that probabilities of alternative, possible outcomes are known. The fact is that in most instances of factory automation, the probabilities are not known and the situation is more one of uncertainty than of risk. There simply are not enough data points as yet to quantify and document proven results. Many of the techniques mentioned in Section 2.4 are therefore rendered less useful. A notable exception is simulation.

Consequently, the influence of management and the ability to translate overall objectives into the decision-making realm is critical. One question which must be addressed is: What is it (in terms of capability) that is being pursued in a given phase of automation? This emphasis is reflected first in the relative weights assigned to the decision criteria (see Implementation Guide) and secondly in the final discrimination between alternatives. Utility theory reflects this managerial input by developing, for instance, conservative (emphasizing avoidance of bad outcomes), liberal (maximizing possible good outcomes), or equally likely decision rules.

5 Conclusion

This project presented the opportunity to explain in some detail the financial and performance measurement aspects of industrial automation with respect to a military repair environment. The case study itself delves into specifics on how to establish performance parameters and compile them into an aggregate term. Also, a scheme for basing implementation rate decisions is developed.

In a more general sense, the literature review and discussions with NADEP personnel provided for a broad appreciation for both the financial and technological concerns in industrial automation. The most prevailing image that one comes away with is the incredible degree of complexity involved in modern manufacturing environments. The sheer number of variables involved is staggering. For instance, consider the scheduling function alone. In large batch operations such as the one at the NADEP, the problem is

non-polynomial(NP)-hard, and must be approached heuristically.

In addressing the implementation issue, a methodology for deciding on the next step of automation is discussed. What remains is a discussion of the *rate* of implementation, which entails some unique considerations in a public venture. First, a projection of performance index goals is established as a standard to measure incremental progress against. Further automation could not be pursued unless these goals were matched. The degree to which they were or were not matched would also yield an indication as to areas of potential improvement (in terms of the individual parameters).

Secondly, and more importantly, is the budgetary consideration. A long-term budget plan for the facilitization of the new production plant has long been approved. Barring unforeseen complications (such as intensified budget cuts), these funds will be released in yearly budget authorizations. Therefore, the issue is more one of how to best *apply* incoming funds than what to do should funds become available. The tools developed here should be of assistance in determining how to effectively manage these funds. The available funding becomes a bounding condition against which to make effective decisions.

Also, the importance of quantifying the benefits becomes somewhat less important in a government venture. Issues of public interest and the strength and responsiveness of the defense industrial base loom large and can oftentimes play a key role in the selection between competing alternatives.

The future of U.S. automation is very much unclear. Manufacturers in this country spend about $17 billion per year on automation, and the market for industrial automation products and services is growing at an estimated 10% per year [48]. Considering the enormous sums of money being expended, the pressing question becomes: "Are manufacturers applying the available technology efficiently, and how can they spend that $17 billion more effectively?"

In a survey conducted in 1986 by Coopers and Lybrand [48] to respond to this question, two points seemed to stand out. First, the manufacturing executives seem to be looking at their domestic competition as the most important gauge for success. They are primarily using U.S. market share as their measure, when it is clear from the results of the past five years that almost every industry is affected significantly by global markets. Secondly, there seems to be a pronounced difference between the way manufacturing executives evaluate their current use of technology and the actual penetration of state-of-the-art technology in the workplace. In other words, meaningful application is lagging good intentions.

It is interesting to note that in the midst of performing an economic evaluation on the NADEP, the new facility has already paid for itself without having repaired a single blade. This is due to the induced competitive price break offered to NADEP by its competitors for those blades that the NADEP contracts out. Such is the effect of negating a monopolistic atmosphere. However, even considering this, it is still appropriate to judge the new facility on its own merit, which this study should help to do.

Table 1: PERFORMANCE INDEX EVALUATION

Parameter						Parameter
Cost/Bld	Thruput	Inv	%Scrap	......	MTTF	Range
$40	30,000	very low	5%	A	8 mos	10
						9
						8
						7
						6
						5
						4
						3
						2
$300	10,000	very high	25%	Z	2 mos	1

Table 2: PERFORMANCE INDEX EVALUATION (CONT'D)

Parameter						Parameter
Cost/Bld	Thruput	Inv	%Scrap	......	MTTF	Range
$40	30,000	very low	5%	A	8 mos	10
†		X‡				9
			X	X		8
	X					7
X						6
					X	5
						4
						3
						2
$300	10,000	very high	25%	Z	2 mos	1
6	7	9	8	8	5	Evaluation Rating
28	25	15	12	......	4	Weight (Sum = 100)
168	175	135	96	96	40	Sum = 710 (/1000)

† incremental values within range

‡ actual parameter rating

Table 3: IMPLEMENTATION GUIDE

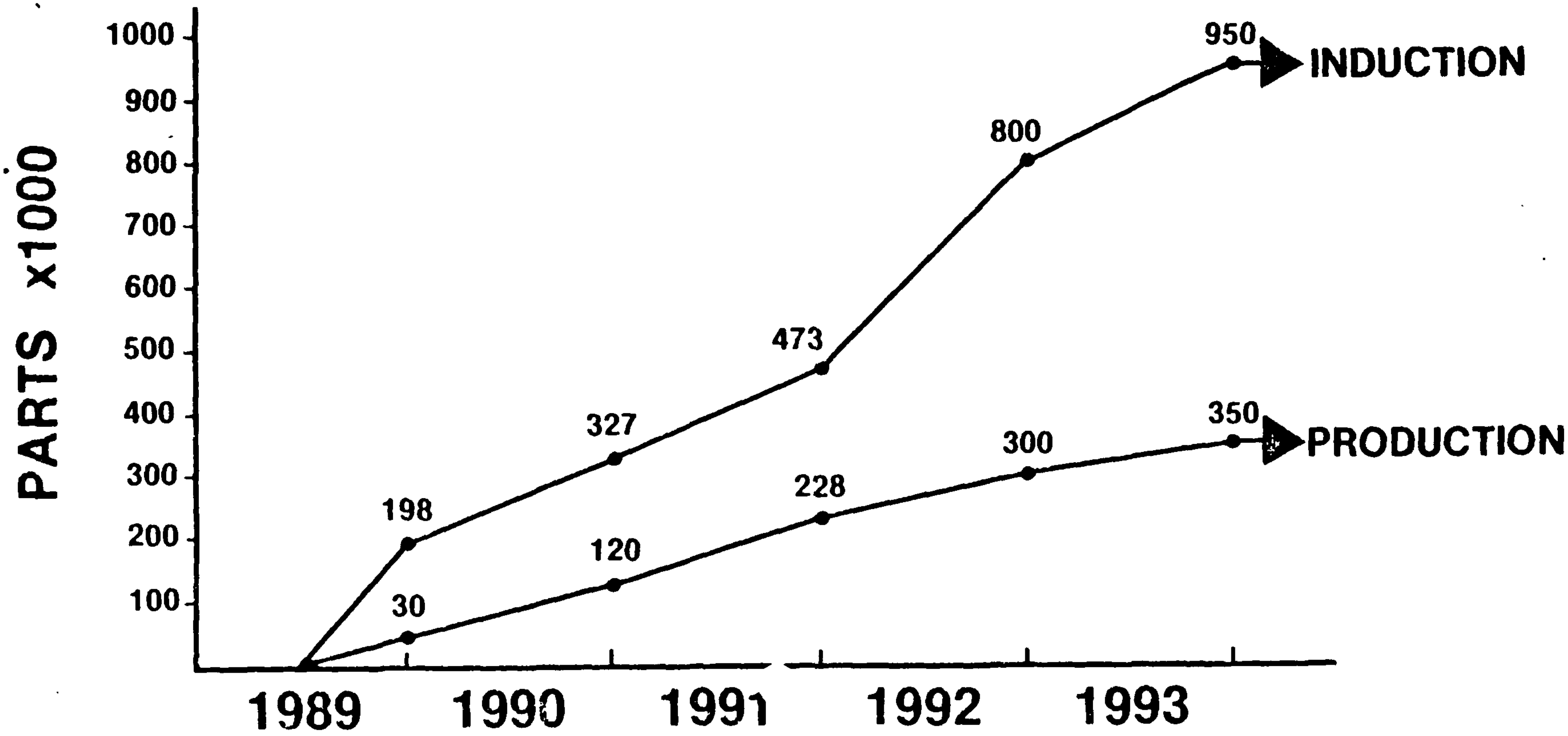
Decision Criteria	Wght	Alternatives' Rating: Nothing	1/4	1/2	3/4	Full	Full +	Range: Worst(1)	Best(10)
Cost/Blade	15							+30%	-100%
Invento.y	10							+25%	-50%
$ Thruput	10							+50%	-50%
Thruput Time	5							+15%	-50%
WIP Vs Idle Time	5							-40%	+20%
% Scrap	5							+20%	-60%
Equip Util	10							-50%	+30%
Reliability	15							-50%	+50%
Integrability	20							+5%	+90%
Other Strategic?	5								
Total Benefit (B)									
Total Cost (C)									

Table 4: IMPLEMENTATION GUIDE (CONT'D)

Decision Criteria	Wght	Alternatives' Rating						Range	
		Nothing	1/4	1/2	3/4	Full	Full +	Worst(1)	Best(10)
Cost/Blade	15	3	2	3	4	7	8	+30%	-100%
Inventory	10	3	4	4	5	6	6	+25%	-50%
$ Thruput	10	5	3	5	6	7	8	+50%	-50%
Thruput Time	5	2	3	5	6	6	5	+15%	-50%
WIP Vs Idle Time	5	6	7	9	10	10	9	-40%	+20%
% Scrap	5	3	3	6	8	6	4	+20%	-60%
Equip Util	10	6	6	6	7	7	7	-50%	+30%
Reliability	15	5	4	5	8	7	4	-50%	+50%
Integrability	20	3	4	6	9	8	7	+5%	+90%
Other Strategic?	5	5	6	8	5	4	3		
Total Benefit (B)		400	395	530	685	700	635		
Total Cost (C)		0	500	1500	2000	3500	4500		

FIGURE 1: BLADE/VANE WORKLOAD SCHEDULE

PROJECTED WORKLOAD: MILCON P-940



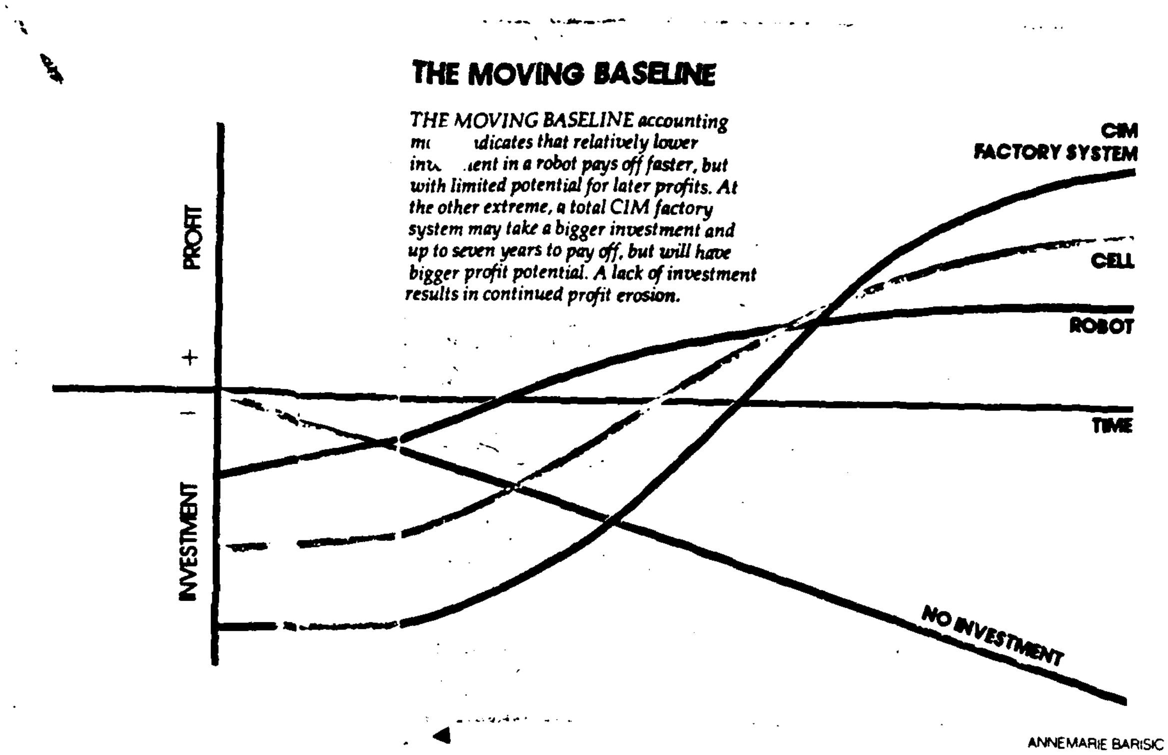


FIGURE 2: RELATIVE COSTS OF CIM TECHNOLOGIES OVER TIME

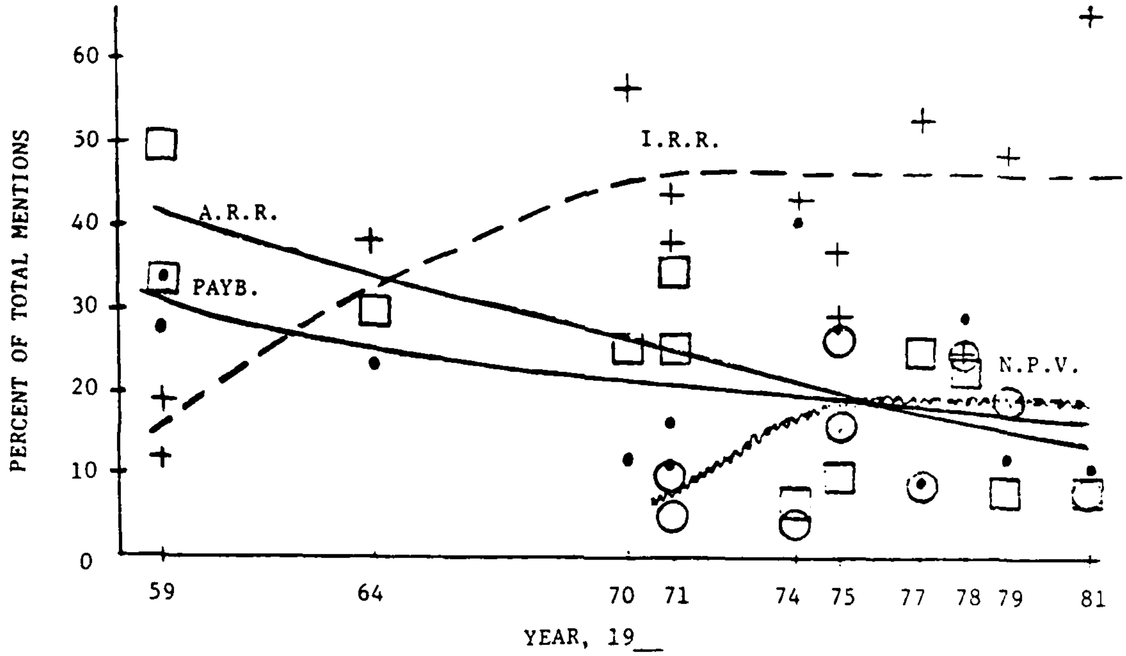
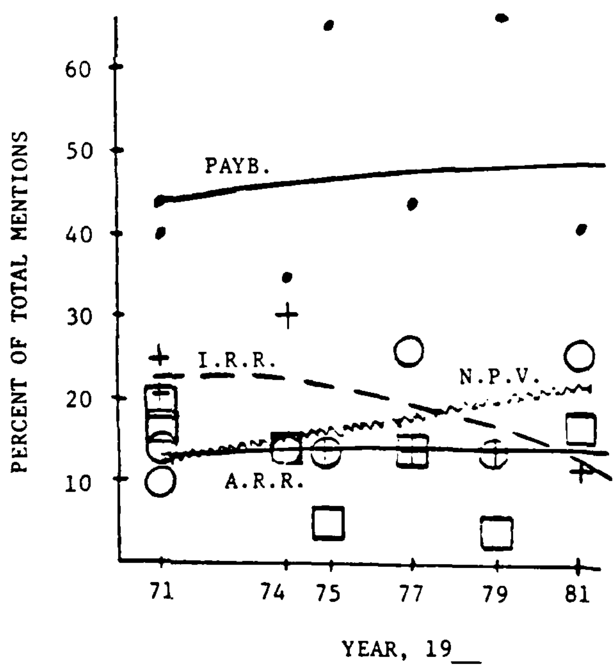


Figure 3

Primary Evaluation Techniques Used Over Time



KEY:

PAYBACK PERIOD (PAYB.)

ACCT'G. RATE OF RETURN (A.R.R.)

INTERNAL RATE OF RETURN (I.R.R.)

NET PRESENT VALUE (N.P.V)

Figure 4

Secondary Evaluation Techniques, If Any, Used Over Time

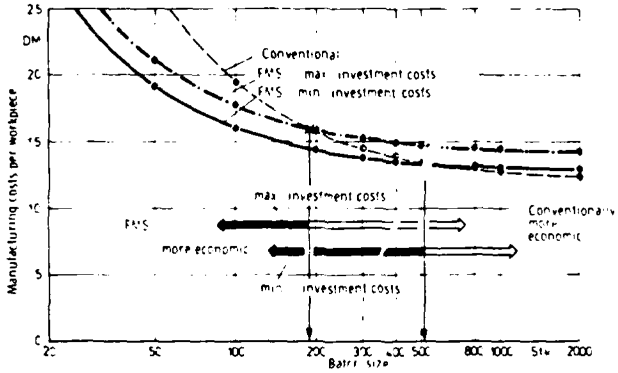


FIGURE 5: INFLUENCE OF INVESTMENT COSTS ON THE LIMITING BATCH SIZE

Appendix

Getting the numbers right

Part I
The cost of capital

A company always has the option of repurchasing its common shares or retiring its debt. Therefore, managers can estimate the cost of capital for a project by taking a weighted average of the current cost of equity and debt at the mix of capital financing typical in the industry. Extensive studies of the returns to investors in equity and fixed-income markets during the past 60 years show that from 1926 to 1984 the average total return (dividends plus price appreciation) from holding a diversified portfolio of common stocks was 11.7% per year. This return already includes the effects of rising price levels. Removing the effects of inflation puts the real (after-inflation) return from investments in common stocks at about 8.5% per year (see *Table A*).*

These historical estimates of 8.5% real (or about 12% nominal) are, however, overestimates of the total cost of capital. From 1926 to 1984, fixed-income securities averaged nominal before-tax returns of less than 5% per year. Taking out inflation reduces the real return (or cost) of high-grade corporate debt securities to about 1.5% per year. Even with recent increases in the real interest rate, a mixture of debt and equity financing produces a total real cost of capital of less than 8%.

Many corporate executives will, no doubt, be highly skeptical that their real cost of capital could be 8% or less. Their disbelief probably comes from making one of two conceptual errors, perhaps both. First, executives often attempt to estimate their current cost of capital by looking at their accounting return on investment – that is, the net income divided by the net invested capital – of their divisions or corporations. For many companies this figure can be in the 15% to 25% range.

There are several reasons, however, why an accounting ROI is a poor estimate of a company's real cost of capital. The accounting ROI figure is distorted by financial accounting conventions such as depreciation method and a variety of capitalization and expense decisions. The ROI figure is also distorted by management's failure to adjust both the net income and the invested capital figures for the effects of inflation, an omission that biases the accounting ROI well above the company's actual real return on investment.

The second conceptual error that makes an 8% real cost of capital sound too low is implicitly to compare it with today's market interest rates and returns on common stocks. These rates incorporate expectations of current and future inflation, but the 8.5% historical return on common stocks and the less than 2% return on fixed-income securities are *real* returns, after the effects of inflation have been netted out.

Now it is possible, of course, to do a DCF analysis by using nominal market returns as a way of estimating a company's cost of capital. In fact, this may even be desirable when you are doing an after-tax cash flow analysis since one of the important cash flows being discounted is the nominal tax depreciation shield from new investments. I have, however, seen many a company go seriously wrong by using a nominal discount rate (say in excess of 15%) while it was assuming level cash flows over the life of their investments.

Consider, for example, the data in *Table B*, which is excerpted from an actual capital authorization request. Notice that all the cash flows during the ten years of the project's expected life are expressed in 1977 dollars, even though the company used a 20% discount rate on the cash flows of the several investment alternatives. This assumption of a 20% cost of capital most likely arose from a prior assumption of a real cost of capital of about 10% and an expected inflation

Table A **Annual return series 1926-1984**

Mean annual returns

Series	**1926-1984**	**1950-1984**	**1975-1984**
Common stocks	11.7%	12.8%	14.7%
Long-term corporate bonds	4.7	4.5	8.4
U.S. Treasury bills	3.4	5.1	9.0
Inflation (CPI)	3.2	4.4	7.4

Real annual returns net of inflation

Series	**1926-1984**	**1950-1984**	**1975-1984**
Common stocks	8.5%	8.4%	7.3%
Long-term corporate bonds	1.5	0.1	1.0
U.S. Treasury bills	0.2	0.6	1.6

rate of 10% per year. But if it believed that inflation would average 10% annually over the life of the project, the company should also have raised the assumed selling price and the unit costs of labor, material, and overhead by their expected price increases over the life of the project.

It is inconsistent to assume a high rate of inflation for the interest rate used in a DCF calculation but a zero rate of price change when you are estimating future net cash flows from an investment. Naturally, this inconsistency – using double-digit discount rates but level cash flows – biases the analysis toward the rejection of new investments, especially those yielding benefits five to ten years into the future. Compounding excessively high interest rates will place a low value on cash flows in these later years: a 20% interest rate, for example, discounts $1.00 to $.40 in five years and to $.16 in ten years. If companies use discount rates derived from current market rates of return, then they must also estimate rates of price and cost changes for all future cash flows.

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